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Observations of V838 Mon and the nearby region in the CO $J = 1 \rightarrow 0$, $2 \rightarrow 1$ and $3 \rightarrow 2$ transitions

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Abstract. We present observations of V838 Mon and its close vicinity in the three lowest rotational transitions of CO. The $J = 2 \rightarrow 1$ and $3 \rightarrow 2$ data were obtained using the 3 m KOSMA telescope. They include on-the-fly maps covering a large area (~3.4 sq. deg.) around V838 Mon and long integrations on the star position. Complementary observations in the CO $J = 1 \rightarrow 0$ transition were obtained using the 13.7 m Delingha telescope. The star position as well as 25 other points preselected in the near vicinity of the object have been measured in this transition.

We report on a detection of two narrow emission components in $J = 2 \rightarrow 1$ and $3 \rightarrow 2$ transitions at the position of V838 Mon. Lines were found at radial velocities of $V_{\rm lsr} = 53.3$ km s^{-1} and $V_{\rm lsr} = -11.0$ km s^{-1}. Their origin is unclear. We also shortly discuss results of the observations of the vicinity of V838 Mon.

1. Introduction

The enigmatic eruption of V838 Mon, followed by its spectacular light echo, triggered research in different fields of astrophysics. Apart from studies of the evolution of the object, investigations of the circumstellar and interstellar neighborhood of the star can also be important for understanding the nature of the event. We present observations undertaken to search for molecular matter in the vicinity of V838 Mon.

Using the results of the CO $J = 1 \rightarrow 0$ galactic survey of Dame et al. (2001) van Loon et al. (2004) have suggested that V838 Mon is situated in a bubble of CO emission of a diameter of about 1° (see Fig. 1). According to these authors the structure is of circumstellar origin due to the AGB activity of the V838 Mon progenitor. Several critical points against this finding and interpretation have been raised in Tylenda et al. (2005). However, the structure in the CO map reported in van Loon et al. (2004) is quite suggestive and we have found important to obtain CO observations of the same ragion with a better sensitivity and angular resolution

There are also other important reasons for observing the star and its vicinity in molecular lines. These are the nature of the echoing matter and a search for matter lost during and after the 2002 outburst. The detection and monitoring of the SiO maser emission from V838 Mon (Deguchi et al. 2005; Claussen et al.

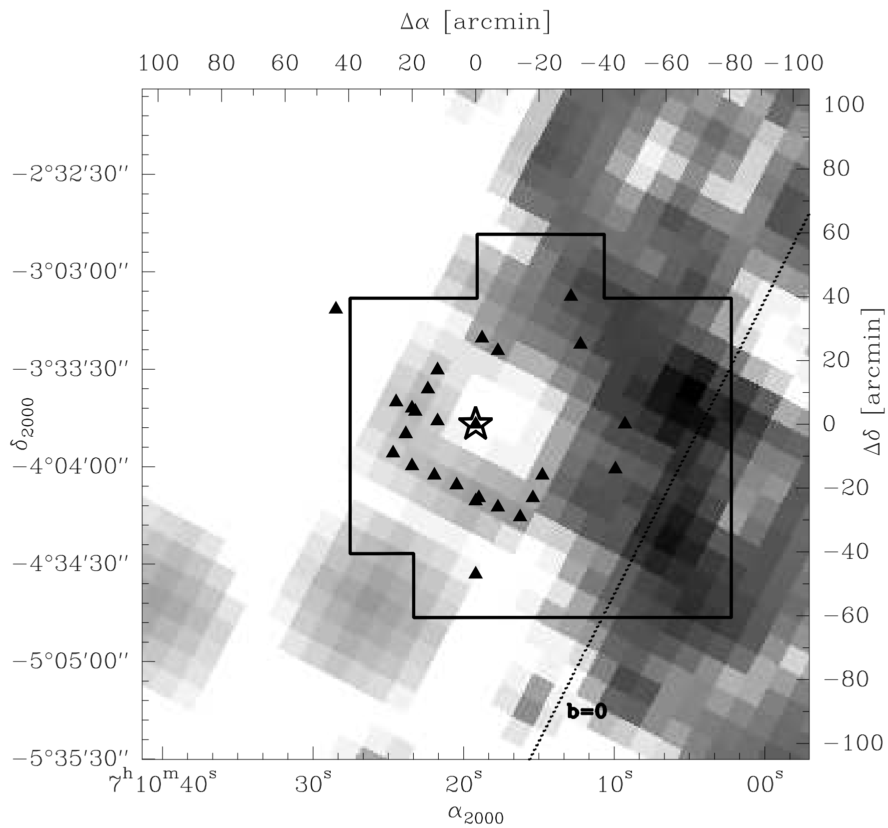

Figure 1. A $3^\circ.5 \times 3^\circ.5$ map centered at the V838 Mon position from the CO (1–0) galactic survey (data taken from *SkyView* – `http://skyview.gsfc.nasa.gov/`; Dame et al. 2001). The star symbol marks V838 Mon position. The polygon drawn with a solid line defines the region observed in the on-the-fly mode in the CO (2–1) and (3–2) transitions. Triangles mark the positions observed in the CO (1–0) transition. Dashed line indicates the Galactic equator.

2005) shows that a molecular activity started close to the star. Complementary observations in molecular thermal transitions would be important to better understand what is going on there.

2. Observations

We performed observations in the three lowest rotational transitions of CO in millimeter and submillimeter wavelengths. Observations in CO $J = 1 \rightarrow 0$ (115.27 GHz) were obtained using the Delingha 13.7 m telescope in October–November 2005. Beside the star position, 25 points in the region around V838 Mon were observed, with majority of them located in the molecular ring claimed in van Loon et al. (2004). All the points observed in CO (1–0) are marked with filled triangles in Fig. 1.

Observations in the higher transitions, i.e. CO $J = 2 \rightarrow 1$ and $3 \rightarrow 2$ (230.54 and 345.80 GHz, respectively), were obtained with the 3 m KOSMA telescope. In April 2005 we made two *on-the-fly* maps with a 1 arcmin spacing and of a total area of 3.4 squared deg. Location of the mapped region is shown on Fig. 1. We also made longer integrations on the V838 Mon position in April and December 2005 in both transitions.

In all the cases heterodyne SIS receivers and acousto–optical spectrographs were used as frontends and backends, respectively.

3. CO regions around V838 Mon

In this section we present observations of the field around V838 Mon in the three transitions, starting from those obtained with the KOSMA telescope and followed by a discussion of the lowest transition observed with the Delingha telescope.

3.1. On-the-fly maps in CO $J = 2 \rightarrow 1$ and $3 \rightarrow 2$

As a result of the on-the-fly observations we have obtained a set of 12 400 spectra for each transition with typical integration time of 4–8 s. Basic technical description of the data is given in Table 1. It should be noted that the sensitivity of the survey in both lines is rather poor. Furthermore, because of changing atmospheric conditions the data quality is not homogeneous. Hence, special data reduction procedures were needed to visualize the data (e.g. clipping method).

From an analysis of the spectra averaged over all the positions and from the channel maps we have found that the molecular emission in the mapped region comes mainly from matter at radial velocities of $V_{\rm lsr}$=18–32 km s^{-1} and $V_{\rm lsr}$=44–57 km s^{-1}. Adopting a galactic rotation curve from Brand & Blitz (1993) the two velocity ranges correspond to kinematical distances of $d_{\rm kin}$=2.3–3.0 kpc and $d_{\rm kin}$=6.2–6.5 kpc, respectively. These values are in good agreement with distances to two spiral arms in the direction of V838 Mon, i.e. Perseus Arm (3 kpc) and Norma–Cygnus Arm (6.25 kpc). We have estimated physical parameters for the clouds emitting in CO. Adopting $d_{\rm kin}$ as distances to these structures we have got values of the physical parameters typical for molecular clouds.

In Fig. 2 we present the map of intensity integrated over two velocity ranges (spectra used to obtain map were earlier clipped at $3\sigma_{\rm rms}$ level) for the CO (2–1) transition. The CO (3–2) map looks similar so we do not present it here. No significant emission can be seen around V838 Mon up to a radius of about 40'. In particular there is no shell-like structure around the star, contrary to the claim of van Loon et al. (2004). All the significant emission west from the star position comes from ordinary giant molecular clouds in the Galactic disk.

Sparks et al. (2006, this issue) have concluded from polarimetric observations of the light echo that the distance to V838 Mon is ~ 5.9 kpc. This value is close to the distance of the outermost spiral arm in the star direction i.e. Norma–Cygnus Arm. Thus V838 Mon is likely to be situated *in* or at least *close to* this spiral arm. This is consistent with the radial velocity of the star of $V_{\rm lsr} = 54.3$ km s^{-1} (Deguchi et al. 2005), the existence of the B3 V companion

Table 1. Characteristics of the observations of the region around V838 Mon in the three lowest rotational transitions of the CO molecule.

CO line	$J = 1 \rightarrow 0$	$J = 2 \rightarrow 1$	$J = 3 \rightarrow 2$
beam	55”	130”	82”
$T_{\rm sys}$ [K]	231 ÷ 286	153 ÷ 230	230 ÷ 377
vel. range [km s^{-1}]	–139 ÷ 189	–106 ÷ 216	–121 ÷ 231
ΔV_{ch} [km s^{-1}]	0.37	0.21	0.29
$< \sigma_{\rm rms} >$ [K]	0.09	0.42	0.93

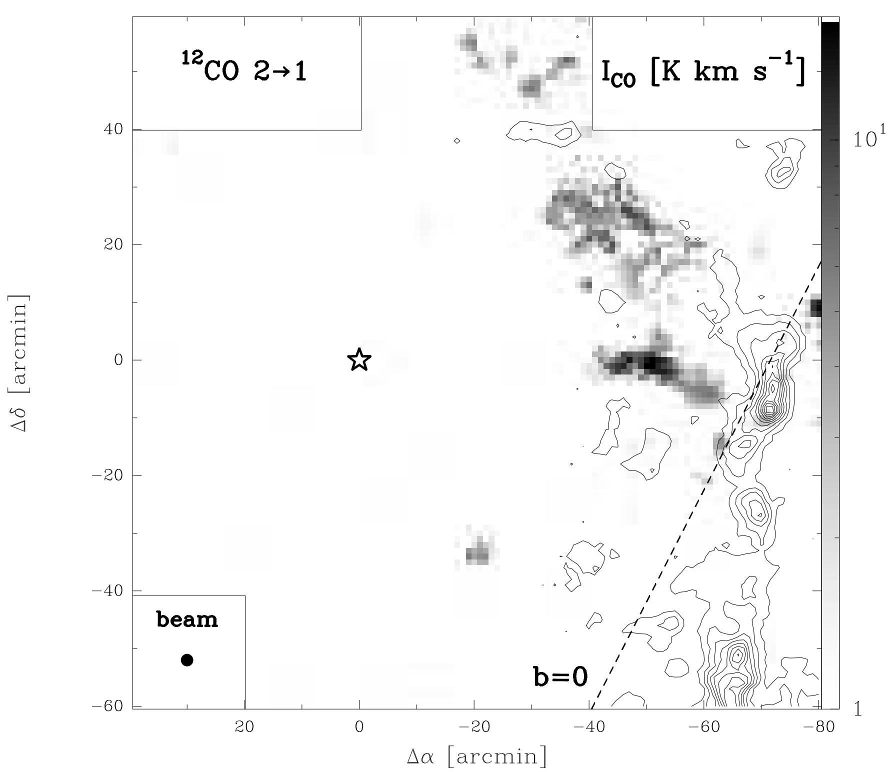

Figure 2. The intensity map of CO $J = 2 \rightarrow 1$ integrated over two velocity ranges: 18–32 km s^{-1} (contours) and 44–57 km s^{-1} (grey scale). Contours are plotted from 2.7 to 64.1 K km s^{-1} by 6.8 K km s^{-1} (4 to 94% by 10% of the maximum). The V838 Mon position is marked a star-like symbol. The Galactic equator is shown as a dashed line.

and the proposed membership of V838 Mon to a young cluster of B-type stars (Bond et al. 2006, this issue).

3.2. Observations in CO $J = 1 \rightarrow 0$

Principle technical details of our observations in CO (1–0) are presented in Table 1. Average $3\sigma_{\rm rms}$ level for these observations is of $\sim$0.3 K, which gives a better sensitivity than that of the Galactic survey by Dame et al. (2001) in the same transition.

Significant CO (1–0) emission is seen only for points west of the star position, in the area where we have also found emission in CO (2–1) and (3–2) (see §3.1). The emission is always related to molecular clouds (what has already been noted by Tylenda et al. 2005). Among the points in the ring-like structure claimed in van Loon et al. (2004) we have found a clear emission only at an offset $\Delta\alpha$=12', $\Delta\delta$=1' (see upper and right axes in Fig. 1, the offset is given in respect to the star position). The emission is weak, $T_A^* \approx$0.6 K, and narrow, ΔV=1.9 km s^{-1}. It is at a radial velocity of $V_{\rm lsr}$=49.2 km s^{-1}, only $\sim$5 km s^{-1} different from the velocity of V838 Mon (54.3 km s^{-1}).

Our observations in CO (1–0) show that the shell-like structure suggested by van Loon et al. (2004) does not exist. Detection of the emission at 12' from the star (20 pc at 6 kpc) suggests that there can be a weak extended molecular emission near V838 Mon, below the sensitivity of our observations. Observations with a better sensitivity are needed to verify if this molecular matter can be related to the echoing matter.

4. Observations at the position of V838 Mon

V838 Mon itself was observed in the three lowest rotational transitions of CO with longer integration times. Observational details are summarized in Table 2.

In the CO (1–0) transition the V838 Mon position was observed only once. We did not find any emission stronger than 0.2 K ($3\sigma_{\rm rms}$). We also observed 8 positions around the star, i.e. points with offsets of ±1', with shorter integration times. In all these positions we did not detect any emission higher than 0.6 K ($3\sigma_{\rm rms}$). The area covered by these 9 points corresponds to that of the light echo in the fall of 2005. Thus the echoing matter is not seen at the sensitivity of our observations.

In CO (2–1) and (3–2) we have spectra obtained in April and December 2005. In the spring spectra we have found emission only in the CO (2–1) transition at a radial velocity of $V_{\rm lsr}$ = 53.4 km s^{-1}, almost the same as the velocity of the SiO maser emission (Deguchi et al. 2005). In the spectra obtained in December with much longer integration times we have found two components in both transitions. Apart from the already known component at $V_{\rm lsr}$ = 53.4 km s^{-1}, an emission is also seen at a radial velocity of $V_{\rm lsr} = -11$ km s^{-1}. The line intensities, widths and peak velocities are presented in Table 3. All the lines are very narrow. The component at $\sim$ 53 km s^{-1} is stronger in the CO (2–1) transition, while that at ~ -11 km s^{-1} is stronger in CO (3–2). When one compares the line intensities in April and December it looks like the strength of the component at $\sim$ 53 km s^{-1} decreased. However, the observed change is close to the measurment uncertainty so this finding is not conclusive.

The beam widths of our observations in CO (2–1) and (3–2) are rather large (130" and 82", respectively). Therefore we cannot say whether the emission detected at the V838 Mon position comes from the closest stellar vicinity or from regions which are located at a few tens of arcmin from the star. It should be noted that a search for molecular emission (including CO and SiO maser) in 2003 gave negative result (Rushton et al. 2003). The detected emission in the CO lines may indicate that a molecular activity has started close to V838 Mon, but its origin is unclear. Further observations with a better angular resolution would be of particular interest in this point.

Table 2. The technical description of the observations at V838 Mon position in the CO lines in 2005.

date	line	$T_{\rm sys}$ [K]	$\Delta\nu_{ch}$ [kHz]	ΔV_{ch} [km s^{-1}]	velocity range [km s^{-1}]	$\sigma_{\rm rms}$ [K]
04 Apr.	2–1	168	165.4	0.21	–106.4 ÷ 171.4	0.043
	3–2	273	339.1	0.29	–121.4 ÷ 186.4	0.083
02 Nov.	1–0	245	142.1	0.37	–139.5 ÷ 188.7	0.072
26 Dec.	2–1	310	165.4	0.21	–206.8 ÷ 233.5	0.014
	3–2	418	339.3	0.29	–289.5 ÷ 250.4	0.022

Table 3. Spectral chracteristics of the CO lines found in the observations at V838 Mon position in 2005.

date	line	$V_{\rm LSR}$ [km s^{-1}]	Peak $T_{\rm mb}$ [K]	FWHM [km s^{-1}]	Int. intensity [K km s^{-1}]
04 Apr.	2–1	53.3	0.553	1.174	0.691
26 Dec.	2–1	–11.1	0.099	1.075	0.114
		53.3	0.323	1.179	0.406
	3–2	–11.0	0.188	1.148	0.230
		53.2	0.156	1.500	0.190

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